AËRIAL LOCOMOTION.

PETTIGREW *versus* MAREY.

BY

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THE great interest taken in aërial locomotion, and the increasing belief in the feasibility of a flying machine, invest works on natural and artificial flight with a rtain significance and importance which cannot be over timated in the present day, characterised as it is by usual progress and invention.

The works to which we wish more especially to direct tention, and which have attracted an unusual share of otice, are those of Dr. J. Bell Pettigrew, of Edinburgh, d Professor E. J. Marey, of Paris.

The names of Dr. Pettigrew and Professor Marey are ell known in the scientific world, and require only to be entioned. Both gentlemen are physiologists of a high der, both have experimented largely on the subject under nsideration, and both, as a consequence, are entitled to heard.

The object of the present article is to show that these *vants,* notwithstanding certain apparent differences (and otwithstanding much that has been written to the con- ary), essentially agree. The fundamental features of ght, according to both, are the same. If there be differ- ces, they refer, for the most part, to time and the mode of eatment adopted, Dr. Pettigrew having published his views me two years before Professor Marey.

Dr. Pettigrew obtained his results by transfixing the domen of insects with a fine needle, and watching the ings vibrate against a dark background, by causing dragon- ies, butterflies, blowflies, wasps, bees, beetles, &c., to fly a large bell jar, one side of which was turned to the light, e other side being rendered opaque by dark pigment; by

throwing young pigeons and birds from the hand into the air for the first time; by repeated observation of the flight of tame and wild birds; by stiffening, by tying up, and by removing portions of the wings of insects and birds; by an analysis of the movements of the travelling surfaces of quadrupeds, amphibia, and fishes; by the application of artificial fins, flippers, tails and wings, to the water and air; and by repeated dissections of all the parts, directly and indirectly, connected with flight.

Professor Marey obtained his results by gilding the extremities and margins of the wings of the insect with minute portions of gold leaf; by the application of the different parts (tip and anterior margin) of the wing of the insect to a smoked cylinder rotating at a given speed, the wing being made to record its own movements; by the captive and free flight of birds, which carried on and between their wings an apparatus which, by the aid of electricity, registered the movements of the wings on a smoked surface, travelling, at a known speed, in a horizontal direction; and by the employment of an artificial wing, constructed on the plan recommended by Borelli, Chabrier, Straus-Durckheim, Girard, and others.

The treatises on flight and cognate subjects by Dr. Pettigrew and Professor Marey are so elaborate and so profusely illustrated,* that a digest of them cannot fail to be interesting to the general reader, the more especially as in that digest we hope to state in a few words, and in something like chronological order, not only the great leading features of flight, but also the points wherein Dr. Pettigrew agrees with and differs from Professor Marey—these not being generally known.

The parts of Dr. Pettigrew's and of Professor Marey's works which interest us most are those which deal with aërial locomotion and the flight of the insect and bird.

Professor Marey, in his recent book,† describes the figure-of-8 movements made by the wing in space, and for these he claims, and in some journals has obtained, considerable *cudos*, although it is difficult to understand on what grounds.

There can be no question of the fact, that the figure-of-8 movements made by the wing in flight *were first observed*,

* Dr. Pettigrew's memoirs alone contain over 200 original figures—those of Professor Marey considerably over 100.

† Animal Mechanism: A Treatise on Terrestrial and Aërial Locomotion. By E. J. Marey, Professor at the College of France, and Member of the Academy of Medicine. Henry S. King and Co. 1874.

described, and *delineated* by Dr. Pettigrew, and to this physiologist undoubtedly belongs the high merit of first discovering the true principles of flight.

Dr. Pettigrew published his discovery in the early part of 1867,* and Professor Marey did not write upon the subject of flight till the end of 1868.† There is, therefore, an interval of nearly *two years* in favour of Dr. Pettigrew.

We think it right to draw attention to this circumstance, because Professor Marey does scant justice to Dr. Pettigrew, and because we detect in all Professor Marey's writings on flight traces of Dr. Pettigrew's original discovery.

This remark applies equally to Professor Marey's theory and practice of flight.

We hope to be able to prove the validity of our position, as we advance, by a series of parallel passages. The history of science demands that this course should be taken. We begin with the figure-of-8 itself.

Professor Marey, in a letter addressed to the French Academy of Sciences, admitted Dr. Pettigrew's claim to priority in the matter of the figure-of-8 movements made by the wing in space in the following terms:—

> "I have ascertained that, in reality, Mr. Pettigrew has seen before me, and represented in his memoir‡ the figure-of-8 track made by the wing of the insect, and that the optic method to which I had recourse is almost identical with his . . . .
>
> "I hasten to satisfy this legitimate demand, and I leave entirely to Mr. Pettigrew the priority over me relatively to the question, as restricted." (Comptes Rendus, May 16th, 1870, p. 1093).

Since writing the above, Professor Marey has evidently been changing his views; for in his new work ("Animal Mechanism," p. 187) he states that, "notwithstanding this apparent agreement, our theory, and that of Dr. Pettigrew, differ materially from each other."

We have searched diligently for the points of *disagreement*, and find them trifling in character and few in number. The points of *agreement*, on the other hand, are numerous and important.

Dr. Pettigrew, in his letter of "reclamation" to the French Academy,|| to which the foregoing, by Professor

* "On the Various Modes of Flight in Relation to Aëronautics." Proceedings of the Royal Institution of Great Britain, March 22, 1867.
"On the Mechanical Appliances by which Flight is attained in the Animal Kingdom." Trans. Linn. Soc., vol. xxvi. (Read June 6th and 20th, 1867).

† Comptes Rendus. Tome lxvii., No. 26, p. 1341. Dec. 28, 1868.

‡ "On the Mechanical Appliances by which Flight is attained in the Animal Kingdom." By J. Bell Pettigrew, M.D., F.R.S. Trans. Linn. Soc., vol. xxvi. (Read to Linn. Soc. on June 6th and 20th, 1867).

|| Comptes Rendus. April, 1870.

Marey, is the reply, claims to have been the first to describe and illustrate the following:—

"1. That quadrupeds walk, and fishes swim, and insects, bats, and birds fly, by *figure-of-*8 movements."
"2. That the flipper of the sea bear, the swimming wing of the penguin, and the wing of the insect, bat, and bird, are screws *structurally*, and resemble the blade of an ordinary screw propeller."
"3. That these organs are screws *functionally*, from their twisting and untwisting, and from their rotating in the direction of their length, when they are made to oscillate."
"4. That they have a reciprocating action, and *reverse their planes* more or less completely at every stroke."
"5. That the wing describes a *figure-of-*8 *track in space*, when the flying animal is artificially fixed."
"6. That the wing, when the flying animal is progressing at a high speed in a horizontal direction, describes a *looped* and then a *waved track*, from the fact that the figure of 8 is gradually opened out or unravelled as the animal advances."
"7. That the *wing acts after the manner of a boy's kite*," both 'during the *down*' and the '*up*' strokes.*

Such are briefly Dr. Pettigrew's views; and if we compare what Professor Marey has written on flight with what Dr. Pettigrew here enunciates, we shall find the coincidences (to use no stronger terms) very striking.

Take the following passages from Professor Marey's recent work as examples:—

"If we gild a large portion of the upper surface of a wasp's wing, taking precautions that the gold leaf should be limited to this surface only, we see that the animal placed in the sun's rays *gives the figure-of-*8 with a very unequal intensity in the two halves of the image. . . . . It is evident that the cause of the phenomenon is to be found in *a change in the plane of the wing*, and consequently in the incidence of the solar rays. . . . . We shall find in the employment of the graphic method new proofs of changes *in the plane of the wing* during flight. . . . . [In this and other quotations the italics are ours.] It is therefore not necessary to look for special muscular actions to produce changes in the *plane of the wing*; these in their turn will give us the key to the oblique *curvilinear movements which produce the figure-of-*8 *course* followed by the insect's wing."—("Animal Mechanism," pp. 188, 197).

In the passages here cited, Professor Marey admits, not only that the wing of the insect makes *a figure-of-*8 *track in space*, but also that the figure-of-8 is produced by *a change of plane in the wing*.

This is an important admission, for Professor Marey copies at page 201 of his book a figure-of-8 representation from Dr. Pettigrew's 1867 memoir,† in which this change of plane is delineated, and states that the arrows in Dr. Pettigrew's figure all point in one direction, and are wrongly

* "On the Physiology of Wings." By J. BELL PETTIGREW, M.D., F.R.S. Trans. Roy. Soc. of Edinburgh, vol. xxvi., p. 332.

† Marey's figure is "Fig. 86, Trajectory of the Wing," p. 201. Pettigrew's figure is at p. 233. Trans. Linn. Soc., 1867., vol. xxvi.

placed. This is a glaring inaccuracy on the part of Professor Marey.

He has in the first place reversed the direction of the arrows in Dr. Pettigrew's figure, and in the second place he makes the half of the figure represent the whole. In Dr. Pettigrew's original figure the arrows are pointing from left to right; whereas in Professor Marey's copy of it, they are pointing from right to left.

In the description given of Dr. Pettigrew's figure, it is distinctly stated that *in extension* the arrows of the figure-of-8 are directed from left to right, but that *in flexion* they are directed from right to left.*

In one complete revolution of the wing, therefore, according to Dr. Pettigrew, the arrows are directed alternately from left to right, and from right to left, and this is precisely what happens in every figure-of-8 delineated by Professor Marey.

Dr. Pettigrew, when speaking of the change of plane occurring during the down and up strokes of the wing of the insect, states that:—

"A figure-of-8 compressed laterally, and placed obliquely with its long axis unning from left to right of the spectator, represents the movement in question.

"The *down* and *up strokes*, as will be seen from this account, *cross each ther*, the wing smiting the air during its descent from above, as in the bird and at, and during its ascent from below, as in the flying fish and boy's kite."†

A little further on, and on the same page of his 1867 nemoir, in which the figure-of-8 and waved tracks made by he wing in stationary and progressive flight are delineated,)r. Pettigrew says:—

"The figure-of-8 action of the wing explains how an insect or bird may fix self in the air, the backward-and-forward reciprocating action of the pinion fording support, but no propulsion. In these instances the backward and rward strokes are made to counterbalance each other. . . . . Although the gure-of-8 represents with considerable fidelity the twisting of the wing upon s axis during extension and flexion, when the insect is playing its wings fore an object, or still better when it is artificially fixed; it is otherwise when e down stroke is added, and the insect is fairly on the wing, and progressing pidly.

"In this case the wing, in virtue of its being carried forward by the body in otion, describes an undulating or spiral course."‡

The figure-of-8 and undulating wave movements originally escribed and figured by Dr. Pettigrew, in March and June,

* According to Dr. Pettigrew *extension* in the insect signifies "the carrying the wing in a forward direction, away from the body; *flexion* meaning the verse, or the drawing of the wing from before, backwards towards the body."—rans. Linn. Soc., vol. xxvi., p. 226).

† On the Mechanical Appliances by which Flight is Attained in the Animal ngdom.

‡ Trans. Linn. Soc., vol. xxvi., p. 233.

1867, have been reproduced by Professor Marey in a variety of forms since December, 1868. They are reproduced in a collective form in Professor Marey's work already referred to, published in 1874.

The importance of the figure-of-8 and wave movements cannot be over estimated, and no one appears to be more keenly alive to their value than Professor Marey himself. When speaking of the figure-of-8 made by the wing in space, originally discovered by Dr. Pettigrew by the aid of the optical method, Professor Marey remarks :—

"We have seen, when treating of the mechanism of insect flight, that the fundamental experiment was that which revealed to us the course of the point of the wing throughout each of its revolutions. Our knowledge of the mechanism of flight naturally flowed, if we may so say, from this first notion."*

Professor Marey here admits that his knowledge of flight is derived from the figure-of-8 revealed by the optical method; but he admitted, as already stated to the French Academy of Sciences, in May, 1870, that the optical method to which he had recourse was nearly identical with that which Dr. Pettigrew employed, and that in reality Dr. Pettigrew had seen before him, and delineated the figure-of-8 track made by the wing of the insect in flight.

If, however, Dr. Pettigrew was the first to observe, describe, and delineate the figure-of-8 made by the wing in space; and if, as Professor Marey states, his knowledge of the mechanism of flight "naturally flowed . . . from this first notion," then it is quite evident, even according to Professor Marey's own showing, that the discovery of the true principles of flight was made by Dr. Pettigrew, and *not by him*. This follows as an inevitable sequence.

It is easy to extend a discovery once made, but the true discoverer is he who first describes and delineates the fundamental principle, and in the present instance that is unquestionably Dr. Pettigrew.

Dr. Pettigrew not only described and delineated the figure-of-8 and waved track made by the wing in space; he also described and figured the several changes of plane occurring in the wing during an entire revolution.

To him, moreover, is to be traced the important discovery of the *torsion* and *forward action* of the wing both during the down and the up strokes. The torsion and forward action of the wing are indispensable in flight.

The body in flight is *dragged* forward, not pushed forward;

* Animal Mechanism, p. 234.

but unless the wings themselves fly forward in curves, both during the down and up strokes, as Dr. Pettigrew explains, the body cannot be transmitted from one point to another. Dr. Pettigrew's experiments with natural and artificial wings are quite decisive on this point, as we have ourselves verified.

Dr. Pettigrew was likewise the first to describe and figure *the ellipse* formed by the wing of the bird, and to point out the difference in the direction of the stroke in the wing of the bird and insect, the stroke in the insect being, as a rule, *nearly horizontal*, that in the bird *nearly vertical*.*

Professor Marey, in his first paper on flight, communicated to the French Academy of Sciences,† delineates the wings of the wasp as making *vertical* figure-of-8 loops. Now this never happens in the wasp. The figure-of-8 loops made by the wing of the wasp, as Dr. Pettigrew has shown, are so oblique as to be *nearly horizontal*.

Professor Marey, in his latest work, has corrected this mistake‡, and has delineated the horizontal figure-of-8 loops made by the wing of the insect in a figure nearly, if not identical, with a similar figure by Dr. Pettigrew.

Professor Marey's figure occurs at page 200 of his new work (1874), that of Dr. Pettigrew's at page 338 of his memoir, "On the Physiology of Wings." (Trans. Roy. Soc. Edin., vol. xxvi., 1870).||

A careful comparison of the figures in question will show that Professor Marey's figure is, or may be, a transcript of Dr. Pettigrew's. And this rem rk applies not only to the figure as a whole, but to all its details; first, to the horizontal direction of the figure-of-8 loops, made by the wing

* The following is the account given by Dr. Pettigrew: "The direction of the stroke varies slightly according to circumstances, but it will be quite proper to assume that the wing of the insect is made to vibrate in a more or less *horizontal* direction, and that of the bird or bat in a more or less *vertical* direction. By a slight alteration in the position of the body, or by a rotation of the wing in the direction of its length, the vertical direction of the stroke is converted into a horizontal direction, and *vice versa*.

"The facility with which the direction of the stroke is changed is greatest in insects; it is not uncommon to see them elevate themselves by a figure-of-8 *horizontal* screwing motion, and then suddenly changing the horizontal screwing into a more *vertical* one, to dart rapidly forward in a curved line."—Trans. Roy. Soc. Edin., vol. xxvi., p. 335.

† Physiologie—Détermination éxperimentale du movement des ailes des insectes pendant le vol. Par M. E. J. Marey. Comptes Rendus, tom. lxvii., No. 26, December 28th, 1868, p. 1341.

‡ Professor Marey remarks—"We need only observe the flight of certain insects, the common fly for instance, and most of the other Diptera, to see that the plane in which the wings move *is not vertical*, but, on the contrary, *very nearly horizontal*."—(Animal Mechanism, 1874, p. 204).

|| Figs. 5 and 6 more especially.

in space; secondly, to the reversal of the planes of the wing as the wing flies to and fro, *i.e.*, during a revolution; and thirdly, to the varying angles made by the surfaces of the wing with the horizon, when the wing is made to vibrate.

Surely this is more than a mere coincidence!

Then how strangely Professor Marey has blundered as to the direction of the stroke, when this is vertical. Thus he represents the wing (p. 195, fig. 82) as descending in a *downward* and *backward* direction, and as ascending in an *upward* and *backward* direction. Now this is simply a *physical* impossibility, and clearly shows that Professor Marey has failed to interpret the tracings obtained from the wing by his so-called graphic method.

The arrows in Professor Marey's figure-of-8 (*vide* figure 82), depicting the movements of the wing in space, should, in reality, be reversed. To get a continuous series of figure-of-8 loops, or of forward curves, characteristic of progressive flight, the wing must descend and ascend always *in a forward direction*, as described and figured by Dr. Pettigrew.* The tracings obtained by Professor Marey himself show this conclusively.

At page 201 of the work under consideration, Professor Marey describes his artificial wing as consisting of a *rigid main rib* in front and a flexible sail behind, from which it follows that he is not even now aware that a natural wing, and a properly constructed artificial one, are *flexible* and *elastic throughout*.

Professor Marey is wrong, when he states that the anterior margin of the wing of the insect *is rigid*. The following are his words:—

"These experiments prove that the insect needs, for the due function of flight, a *rigid main rib* and a flexible membrane. If we cover the flexible part of the wing with a coating which hardens as it dries, *flight is prevented*. We hinder it also *by destroying the rigidity of the anterior nervure*."—P. 208.

Dr. Pettigrew, in his memoir "On the Physiology of Wings," expresses the facts in very few words:—

"The wing of a flying creature . . . . *is not rigid*.† . . . That the anterior

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* According to this authority, "a natural wing, or a properly constructed artificial one, cannot be depressed either *vertically downwards*, or *downwards and backwards*. It *will* (the writer would say '*does*') of necessity descend *downwards* and *forwards in a curve*. This arises from its being flexible and elastic throughout, and in especial from its being carefully graduated as regards thickness, the tip being thinner and more elastic than the root, and the *posterior margin* than the *anterior margin*."

† This is again insisted upon in "Animal Locomotion," p. 240, where Dr. Pettigrew remarks, when speaking of the construction of an artificial wave wing on the insect type, "It should be *flexible and elastic throughout*."

margin of the wing should not be composed of a rigid rod may be demonstrated in a variety of ways. If a rigid rod be made to vibrate by the hand, the vibration is not smooth and continuous; on the contrary, it is irregular and jerky, and characterised by two *pauses*, the one occurring at the end of the *up stroke*, the other occurring at the end of the *down stroke*. The wing to be effective as an elevating and propelling organ should have no dead points, and should be characterised by a rapid winnowing or fanning motion. . . . . If a longitudinal section of bamboo cane has added to it tapering rods of whalebone which radiate in an outward direction, and this (framework)* be covered by a thin sheet of india-rubber (gutta-percha tissue), an artificial wing, resembling the natural one in all its essential points, is at once produced. . . . . If this wing be made to vibrate by its root, a series of longitudinal and transverse waves are at once formed, the one series running in the direction of the *length of the wing*, the other in the direction of its *breadth*. The wing further *twists* and *untwists* during the down and up strokes. . . . . This form of wing, which may be regarded as the realisation of the figure-of-8 theory of flight, elevates and propels both during the down and up strokes, and its working is accompanied with almost no slip. It seems literally to float upon the air.†

"*No wing that is rigid in the anterior margin can twist and untwist during its action, and produce the figure-of-8 curves generated by the living wing.* To produce the curves in question, the wing must be flexible, elastic, and capable of change of form in all its parts."‡

In one part of his new work, indeed (viz., at p. 198), Professor Marey seems to have largely profited by the observations and experiments of Dr. Pettigrew, as given above; for he states that, if rapid to-and-fro movements in a vertical plane be given to a "*flexible shaft*" (mark, the shaft is no longer described as *rigid*), to which he affixes a membrane similar to that found in the wings of insects—to use his own words—this *flexible shaft* will then represent the main rib of the wing; and we shall see this contrivance execute all the movements which the wing of the insect describes in space." "If," he says, "we illuminate the extremity of this artificial wing, we shall see that its point describes the figure 8 like a *real wing*; we shall observe also that *the plane of the wing changes twice during each revolution*, in the same manner as in the insect itself."—("Animal Mechanism," p. 198).||

Professor Marey, it will be observed, claims for his artificial wing similar properties to those originally claimed by Dr. Pettigrew for his artificial wing. Thus Dr. Pettigrew states (*op. cit.*, pp. 421, 422), that if the anterior or thick margin of his artificial wave wing be directed upwards, and

* The words in brackets are ours.

† Trans. Roy. Soc. Edin., vol. xxvi., 1870, pp. 408, 419, 420, and 422.

‡ Physiology of Wings. By J. Bell Pettigrew, M.D., F.R.S., p. 422. (Trans. Roy. Soc. Edin., vol. xxvi., 1870).

|| The above remarks of Professor Marey are worth studying; for two reasons: first, because they are so confirmatory of all Dr. Pettigrew had written about the *flexibility* of the main nervure of an insect's wing; secondly, they contrast so strangely with the *rigid* main rib, at pp. 201 and 208 of Marey's work before cited."

the wing made to vibrate, it will fly in *an upward direction* with an undulating motion; that if the anterior or thick margin of the wing be directed downwards, the wing will describe a waved track and fly *downwards;* and if the under surface of the wing makes no angle, or a very small angle with the horizon, it will dart forward in a series of curves *in a horizontal direction.*

Similarly, Prof. Marey says (p. 207) that if the anterior margins of the main ribs of his artificial insect be inclined upwards, the insect *rises vertically*, and that if the anterior margins of the main ribs be turned downwards *a descending vertical force is developed*; and that if the main ribs be turned upwards, and slightly forward, it developes the force *which sustains it in the air*, and directs its course in space.

We may point out many other parallel passages. Dr. Pettigrew states (*op. cit.*, p. 335)—

"The direction of the stroke varies slightly, according to circumstances; but it will be quite proper to assume that the wing of the insect is made to vibrate in a more or less *horizontal direction*, and that of the bird and bat in a more or less *vertical direction*. By a slight alteration in the position of the body or by a rotation of the wing in the direction of its length, the vertical direction of the stroke is converted into a horizontal direction, and *vice versa*.

"The facility with which the direction of the stroke is changed is greatest in insects; it is not uncommon to see them elevate themselves by a figure-of-8 *horizontal* screwing movement, and then suddenly changing the horizontal screwing into a more vertical one, to dart rapidly forward in a curved line."

Compare with the foregoing the following from Professor Marey's new work (p. 207):—

"When an insect hovers over a flower, and we see it illuminated obliquely by the setting sun, we may satisfy ourselves that the plane of oscillation of its wings is *nearly horizontal.* This inclination must evidently be *modified* as soon as the insect wishes to dart off rapidly in any direction; but then the eye can scarcely follow it and detect the change of plane, the existence of which we are compelled to admit by the theory and the experiments already detailed."

When speaking of the wing of the bird, Dr. Pettigrew points out (Trans. Linn. Soc., vol. xxvi., p. 242) that—

"The anterior or thick margin of the wing and the posterior or thin margin present different degrees of curvature, so that under certain conditions the two margins cross each other, and form *a true helix.* The anterior margin presents two well-marked curves, a corresponding number being found on the posterior margin.

"These curves may, for the sake of clearness, be divided into *axillary* and *distal* curves; the former occurring towards the root of the wing, the latter towards the extremity.

"The anterior, axillary, and distal curves completely reverse themselves during the acts of extension and flexion, and so of the posterior, axillary, and distal curves."

In like manner Prof. Marey, in his *first* chapter on the flight of birds (at p. 210), says that—

"If we take a dead bird and spread out its wings . . . we see that, at different points in its length, the wing presents *very remarkable changes of plane.*

At the inner part, towards the body, *the wing inclines considerably both downwards and backwards*, while near its extremity it is *horizontal*, and *sometimes slightly turned up*, so that its under surface is directed somewhat backward."*

It is worthy of remark that the curves of the wing described and delineated by Dr. Pettigrew are reproduced by Prof. Marey (compare Figs. 68, 69, and 70 of Dr. Pettigrew's 1867 memoir, Linn. Soc. Trans., vol. xxvi., with the right wing, Fig. 89, p. 210, of Prof. Marey's new volume).

When speaking of the duration of the down and up strokes, Dr. Pettigrew observes (Trans. Linn. Soc., vol. xxvi., p. 261) :—

"In birds which glide or skim, it has appeared to me that the *wing is recovered much more quickly*, and *the downward stroke is delivered much more slowly*, than in ordinary flight; in fact, that the rapidity with which the wing acts in an upward and downward direction is, in some instances, more or less reversed; and this is what we would naturally expect if we recollect that in gliding the wings require to be, for the most part, in the expanded condition."

Prof. Marey writes in a similar strain. He states—

"Experiment proves that the wing of the bird is raised more quickly than it descends."—(P. 212.) . . . "Contrary to the opinion entertained by some writers, *the duration of the depression of the wing is usually longer than that of its rise.* The inequality of these two periods is more distinctly seen in birds whose wings have a large surface and which beat slowly."—(P. 228.)

Weight, according to Dr. Pettigrew, contributes to horizontal flight. In illustration he states (Trans. Roy. Soc. Edin., vol. xxvi., pp. 355, 356—

"If two quill-feathers are fixed in an ordinary cork, and the apparatus allowed to drop from a height, the cork does not fall vertically downwards, but *downwards and forwards in a curve.* When artificial wings, constructed on the principle of natural ones, are allowed to drop from a height, they *describe double curves* in falling, the roots of the wing reaching the ground first, which proves the greater buoying power of the tips of the wings. Weight, when acting upon wings, must be regarded as an independent moving power." . . . "The *wings of the bird form a natural parachute*, from which the body depends both during the down and up strokes."—(P. 371.)

Prof. Marey performs similar experiments, and arrives at similar conclusions. Thus he explains (p. 217) that if a sheet of paper folded in the middle, with a wire loaded at one end and fixed in the bent portion, be allowed to fall, the apparatus will not descend vertically, but will follow an *oblique trajectory*; and that if the corners of the paper be bent, and the concavity directed downwards, the apparatus will in falling describe a *double curve.*

"The wings are attached exactly at the highest part of the thorax, and consequently, when the outstretched wings act upon the air as a fulcrum, all the weight of the body is placed below this surface of suspension. Thus the

* It is evident, from the succeeding paragraph to above quotation from "Animal Mechanism," that Prof. Marey had read Dr. Pettigrew's observations to which we have just referred.

heaviest part is placed as low as possible beneath the point of suspension. The bird, as it descends with its wings outspread, will thus present its ventral region downwards, without its being necessary to make an effort to keep its equilibrium; it will take this position passively, *like a parachute set free in space*, or like the *shuttlecock when it falls upon the battledore*."—("Animal Mechanism," p. 216.)

Dr. Pettigrew likens the wing of the bird to a boy's kite (Proc. Roy. Inst. of Great Britain, March 22, 1867)—

"The wing of the bird *acts after the manner of a boy's kite*, the only difference being that the kite is pulled forwards upon the wind *by the string and the hand*, whereas in the bird the wing is pushed forwards on the wind by *the weight of the body* and the life residing in the pinion itself."

Similar in substance is the subjoined passage from Prof. Marey (p. 220):—

"In the last two forms, the wing, directed more or less obliquely, derives its point of resistance from the air, *like the child's plaything called a kite*, but with this difference—that the velocity is given to the kite by *the tractile force exerted on the string* when the air is calm, while the bird when it hovers utilises the speed which it has already acquired either by *its oblique fall* or by the previous flapping of its wings."

Dr. Pettigrew attaches great importance to the activity of the wing and its small size. Thus he remarks (Trans. Roy. Soc. Edin., vol. xxvi., p. 408)—

"*The surface exposed by a natural wing*, when compared with the great weight it is capable of elevating, *is remarkably small*. This is accounted for by the length and *great range of motion* of natural wings, the latter enabling the wings to convert large tracts of air into supporting areas. It is also accounted for by the *multiplicity of the movements of natural wings*, these enabling the pinions to create and rise upon currents of their own forming, and to select and utilise existing currents." . . . "The *problem of flight would seem to resolve itself into one of weight, power, velocity, and small surfaces*, as against comparative levity, debility, diminished speed, and extensive surfaces."—(P. 386.)

Analogous in many respects to the foregoing is the following from Prof. Marey (p. 222):—

"The part played by the wing in flight is not merely passive, for a sail or a parachute ought always to have a surface in proportion to the weight which it has to support; but, on the contrary, when considered in its proper point of view, *as an organ which strikes the air*, the wing of the bird ought, as we shall see, to present a surface *relatively less in birds of a large size and of great weight*."

Again:—

"Animals of large size and great weight sustain themselves in the air *with a much less proportionate surface of wing* than those of smaller size."—(P. 222.)

Dr. Pettigrew dwells upon the relative speed attained by the different parts of the wing (Trans. Roy. Soc. Edin., vol. xxvi., pp. 399—442). He says the wing as a rule is long and narrow.

"As a consequence *a comparatively slow and very limited movement at the root confers great range and immense speed at the tip*, the speed of each portion

of the wing increasing as the root of the wing is receded from." . . . "The small humming bird, in order to keep itself stationary before a flower, requires to oscillate its tiny wings with great rapidity, whereas the large humming bird can attain the same object by flapping its large wings with a very slow and powerful movement." . . . "In the larger birds the movements are slower in proportion to the size, and more especially in proportion to the length, of the wing. This leads me to conclude that *very large wings may be driven with a comparatively slow motion.*"

Professor Marey illustrates the same points as under (p. 224):—

"It is not immaterial whether the surface which strikes the air has its maximum near the *body* or near the *extremity ; these two points have very different velocities.* For an equal extent of surface the resistance will be greater at the point of the wing than at its base."

Again (p. 226):—

"It can be proved that, if the strokes of the wing were as frequent in large as in small birds, each stroke would have a velocity whose value would increase with the size of the bird; and as the resistance of the air increases, for each element of the surface of the wing, according to the square of the velocity of that organ, *a considerable advantage would result to the bird of large size, as to the work produced upon the air.*"

Dr. Pettigrew shows that the vigour with which the wing is propelled varies according as the bird is rising, falling, or progressing in a horizontal direction (Trans. Linn. Soc., vol. xxvi., pp. 227, 260, 261). He observes:—

"All birds which do not, like the swallow and humming birds, drop from a height, raise themselves at first by a vigorous leap, in which they incline their bodies in an upward direction. *By a few sweeping strokes*, delivered downwards and forwards, in which the wings are nearly made to meet above and below the body, they lever themselves upwards and forwards, and in a surprisingly short space of time acquire that degree of momentum which greatly assists them in their future career." . . . "The forward movement of the wing during the down or effective stroke is particularly evident in birds when rising, the wing on such occasions being urged with *unusual vigour.*"—(P. 227, *op. cit.*)

"When the bird has elevated itself to the desired height, *the length of the downward stroke is generally curtailed*, the mere extension and flexion of the wing, assisted by the weight of the body, in some cases sufficing for the ordinary purposes of flight. This is especially the case if the bird is advancing against a slight breeze."—(Pp. 260 and 261.) "If birds wish to descend, they may reverse the direction of the inclined plane, and plunge head foremost with extended wings; or they may flex the wings, and so accelerate their pace ; or they may raise their wings, and drop parachute fashion ; or they may even fly in a downward direction—*a few sudden strokes*, a more or less abrupt curve, and a certain degree of horizontal movement, being in either case necessary to break the fall previous to alighting."—(P. 262, *op. cit.*)

Prof. Marey, as the annexed passages show, also adverts to the relative frequency and force with which the wing is urged in ascending, descending, and horizontal flight, though less fully than Dr. Pettigrew does:—

"The frequency of the strokes of the wing varies also according as the bird is first starting in full flight or at the end of its flight."—(P. 228, "Animal Mechanism.")

Again :—

"Confining the question within these limits, experiment shows that the strokes of the bird's wing *differ in amplitude and in frequency* from one moment to another as they fly. When they first start *the strokes are rather fewer, but much more energetic;* they reach, after two or three strokes of the wing, *a rhythm almost regular, which they lose again when they are about to settle.*" —(P. 234, *op. cit.*)

Dr. Pettigrew lays especial emphasis on the elliptical movements made by the wing of the bird (Trans. Linn. Soc., vol. xxvi.) Thus he remarks :—

"During extension the elbow and bones of the fore-arm, particularly their distal extremities, describe an *upward curve.* During flexion the elbow and bones referred to describe another but *opposite curve.* The movements described by the elbow-joint during extension and flexion may consequently be represented by an *ellipse or ovoid.*"—(P. 248, *op. cit.*, Diagrams 8 to 13 more especially.)

Prof. Marey follows Dr. Pettigrew in the matter of these elliptical movements. He says :—

"During the whole of the bird's flight the registering lever described *a kind of ellipse.*" . . . "All our experiments have shown that birds of different species describe with their wings *an elliptical trajectory.*"—(P. 242.)

Again :—

"In fact, the bone of the wing in each describes a kind of *irregular ellipse*, with its greater axis inclined *downwards and forwards.*"

Dr. Pettigrew represents the wing of the bird as oscillating on two separate axes,—the one running parallel with the bird, the other at right angles to it,—and adds (in his 1867 memoir to the Linnean Society, p. 243)—

"The wing may be said to agitate the air in two principal directions, viz., from *within outward or the reverse*, and from *behind forward or the reverse*, the agitation in question producing two powerful pulsations—a longitudinal and a lateral."

Prof. Marey gives, more briefly but yet in very similar terms, the same statement. He says (p. 247)—

"That a bird passes through a *double oscillatory movement*, in a vertical plane, for each revolution of its wings."

Dr. Pettigrew describes and delineates the wing of the bird as advancing in a curved line, both when it rises and falls. He observes (Trans. Linn. Soc., vol. xxvi., pp. 214 and 233)—

"In the water the wing strikes *downwards and backwards* (and acts as an auxiliary of the foot), whereas in the air it strikes *downwards and forwards.* . . . To counteract the tendency of the bird in motion to fall in a downward and forward direction, the stroke is delivered in the direction in which falling would naturally occur,—the kite-like action of the wing, and the rapidity with which it is moved, causing the mass of the bird to pursue a more or less horizontal direction. I offer this explanation of the action of the wing in and out of the water after repeated and careful observation in tame and wild birds, and, as I am aware, in opposition to all previous writers on the subject."

Prof. Marey again corroborates Dr. Pettigrew's original observations, as the subjoined extract from "Animal Mechanism" will show (p. 254) :—

"The inspection of the curve shows us also that the pigeon's wing was carried more especially in the direction of the upper parts, similar to the point A; in other terms, that *the forward predominated over the backward movement.*"

Dr. Pettigrew describes and figures the body of the bird in flight as alternately rising and falling in forward curves, the curves described by the body being the opposite of those described by the wing, those movements being due to a kite-like action of the wings (Trans. Roy. Soc. Edin., vol. xxvi., pp. 343, 344). Thus Dr. Pettigrew remarks :—

"It is a condition of natural wings, and of artificial wings constructed on the principle of living wings, that, when forcibly elevated or depressed, even in a strictly vertical direction, they inevitably dart forward. In both cases the wing describes *a waved track*, which clearly shows that the wing strikes downwards and forwards during the down stroke, and upwards and forwards during the up stroke. The wing, in fact, is always advancing, *its under surface attacking the air like a boy's kite.*" . . . . "As the body of the insect, bat, and bird, falls forward in a curve when the wing ascends, and is elevated in a curve when the wing descends, it follows that *the trunk of the animal is urged along a waved line.* I have distinctly seen the alternate rise and fall of the body and wing, when watching the flight of the gull from the stern of a steamboat."

Professor Marey writes in a very similar strain. He asks (pp. 264, 265) :—

"But do we find that the bird, when suspended in the air, keeps at a constant level, or *does it pass through oscillations in the vertical plane?* Do we not experience, by the intermittent effect of the flapping of its wings, *rising and falling motions*, of which the eye can detect neither the frequency nor extent? Again, does not the bird advance in its onward course, with variable rapidity? Shall we not find in the action of its wings a *series of impulses*, which give to its advancing course a *jerking motion?* These queries can be answered experimentally." . . . . "To explain the ascent of the bird during the time of the elevation of the wing, it seems indispensable to refer to *the effect of the child's kite*, to which we have before alluded. The bird, having acquired a certain velocity, presents its wings to the air *as inclined planes.*" . . . . "Thus, by registering at the same time the two orders of oscillation in the flight of a buzzard, we find that the phase of *depression of the wing* produces at the same time the *elevation of the bird* and the acceleration of its horizontal swiftness."—(P. 269). . . . "A part of this resistance, viz., that which is applied to *the lower surface of the wing*, is utilised to sustain the bird by the kind of action which we have compared to that of *a child's kite*. It appears that this action is of primary importance in the flight of the bird."—(P. 275). . . . "In the bird, one of the phases of the movement of the wing is, to a certain extent, passive; that is to say, it receives the pressure of the air *on its lower surface, when the bird is projected rapidly forward by its acquired velocity.* Under these conditions, the whole bird, being carried forward in space, all the parts of the wing are moved with the same rapidity, to take advantage of the action of the air, *which presses on them as on a kite.*"—(P. 276).

Dr. Pettigrew explains that the wing is a screw structurally and functionally; that it revolves on two axes (the one

running in the direction of the length of the wing, the other in the direction of its breadth), and that the action of the wing resembles the action of an oar in sculling. (Trans. Linn. Soc., vol. xxvi., pp. 206, 229, 231, and 266; Proc. Roy. Inst. of Gt. Britain, March 22, 1867). Thus, he states that:—

"In the fish, the lower half of the body and the broadly expanded tail are applied to the water *very much as an oar is in sculling.*" . . . . The fish may be said to drill the water in two directions, viz., from behind forward, by a *twisting or screwing* of the body on its long axis, and from side to side by causing its anterior and posterior portions to assume opposite curves. The pectoral and other fins are also thrown into curves in action, the movement, as in the body itself, travelling *in spiral waves*; and it is worthy of remark that the wing of the insect, bat, and bird obeys similar impulses.

"The fins *are rotated or twisted*, and their free margins lashed about by spiral movements, which closely resemble those by which the wings of insects are propelled. . . . . That the wing *twists upon itself structurally*, not only in the insect, but also in the bat and bird—anyone may readily satisfy himself by a careful examination; and that it *twists upon itself during its action* I have had the most convincing and repeated proofs." "The wing of the bird acts *as a twisted inclined plane.* In this respect it intimately agrees with the wing of both the insect and bat. . . . . The twisting in question is most marked in the posterior, or thin margin of the wing, the anterior or thicker margin performing more *the part* of *an axis.* As the result of this arrangement, the anterior or thick margin cuts into the air quietly, and as it were by stealth, the posterior one producing on all occasions *a violent commotion*, especially perceptible if a flame be exposed behind the insect."

Professor Marey goes over the same ground in much the same way. Thus, at pages 107, 109, 198, 208, 210, 211, 259, and 261, he states:—

"The oar is found in many insects which move on the surface of the water. A contrivance is employed by other animals, which resembles the action of an oar used at the stern of a boat in the process called *sculling.* To the latter motive power may be referred all those movements in which *an inclined plane* is displaced in the liquid, and finds in the resistance of the water which it presses obliquely two component forces, of which one furnishes a movement of propulsion." . . . . "When a fish strikes the water with his tail, in order to drive himself forward, he executes a double work, a part tends to drive behind him a certain mass of fluid with a certain velocity, and the other to drive the animal forward, in spite of the resistance of the surrounding water. . . . . *Aërial Locomotion.*—This mechanism is still the same; the motion of *an inclined plane*, which causes motion through the air, the wing in fact, in the insect as well as in the bird, strikes the air *in an oblique manner*, repels it in a certain direction, and gives the body a motion directly opposite." . . . . . "Each stroke of the wing *acts upon the air obliquely*, and neutralises its resistance, so that a horizontal force results, which impels the insect forward. An effect is produced analogous with that which takes place when an oar is used in the stern of a boat in the *action of sculling.*" "Most of the propellers which act in water overcome the resistance of the fluid by the action of *an inclined plane.* The tail of the fish produces a propulsion of this kind. *Even the screw may be considered as an inclined plane*, whose movement is continuous, and always in the same direction. . . . . We see the main rib (anterior margin) of the wing remain *sensibly immovable, and around it turns the membranous portion* (posterior margin). . . . . "If this motion as on a pivot did not exist, the wing would cut the air with its edge, and would be utterly incapable of producing flight." . . . . The wing presents *very remarkable changes* of *plane* at the *inner part towards* the body; the wing

iclines considerably, both downwards and *backwards*; while near its extremity : is *horizontal and somewhat slighty turned up*." . . . . We admit that the ‹ing *revolves on an axis*." . . . . "It was necessary therefore, for the lever, ‹hile fixed to the feathers of the bird, to glide freely on the rod in the direction ‹f its length; and yet that it should cause it to receive, under the *form of ›rsion*, all the changes of inclination that are transmitted to it by the wings f the bird." . . . . "For this purpose we must return *to the dotted figure* 8, ‹hich is the impression of the *torsions of the wing* of the different instants."

Dr. Pettigrew points out that the wing acts as a true ‹ite, both during the down and up strokes. He remarks—'Trans. Roy. Soc. Edin., vol. xxvi., p. 343) :—

"If, as I have endeavoured to explain, the wing, even when elevated and epressed in a strictly vertical direction, inevitably and invariably darts for‹ard, it follows, as a consequence. that the wing flies forwards as a true kite, oth during the down and up strokes, and that its *under concave, or biting ‹rface*, in virtue of the forward travel communicated to it by the body in ıotion, is *closely applied to the air, both during its ascent and descent*; a fact itherto overlooked, but one of considerable importance, as showing how the ‹ing furnishes a persistent buoyancy alike when it rises and falls. The angle ıade by the wing of the bat and bird with the horizon is constantly varying, ; in the insect wing."

Professor Marey, in his earlier writings ("Revue des ‹ours Scientifiques de la France et de l'Etranger," Mars, '869) describes the wing as making *a backward angle of 5° with the horizon during its descent, and a forward angle ‹f 45° during its ascent.*

This view was shown by Dr. Pettigrew to be untenable, ‹nd we find it greatly modified in Professor Marey's later work. ‹hus, at fig. 111, p. 263, where the angles of inclination ıade by the wing during its rise and fall are given, the ‹nder surface of the wing is represented as *forming a kite*, ‹uring quite three-fourths of one entire revolution of the ‹ing.

At no point is the wing represented as making, during its escent, *a backward angle of* 45°. Nor is this all. At p. 274, 'rofessor Marey states that—

"In free flight the axis of the bird is horizontal, or rather *turned somewhat ›ward.* Restored to this proper position, a fresh direction would be given to ‹ch of the positions of the wing. Then, probably, we should see that the ‹ing always *presents its lower surface to the air*, as the only one which can ıd in it a point of resistance."

In this modified statement, as may readily be perceived, ‹e have simply a repetition of Dr. Pettigrew's view, viz., *that the under surface of the wing acts as a kite, both when ‹e wing rises and falls*."

We might greatly multiply these parallel passages in ‹roof of our original assertion, that in all Professor Marey's ‹ritings and experiments in flight, *Dr. Pettigrew's original ‹iscoveries and experiments may be traced*, and we may fairly

emphasise our other statement, "*that Professor Marey has done scant justice to Dr. Pettigrew.*

This is the more evident, as we are given to understand that Dr. Pettigrew's original memoirs and papers were duly transmitted to Professor Marey immediately after their publication.

From the foregoing, it will be evident that Professor Marey has added comparatively little to the science of Aërostation. He has, for the most part, simply confirmed by experimental methods, in which he is an adept, Dr. Pettigrew's original observations and experiments, published nearly two years before his own experiments were undertaken.

Professor Marey is certainly not entitled to say, as he does at p. 187, that "*notwithstanding this apparent agreement, our theory and that of Dr. Pettigrew differ materially from each other.*"

Still less is he entitled, virtually, to appropriate Dr. Pettigrew's descriptions and figures, without full and fair acknowledgment. Least of all is he entitled to modify and misrepresent those descriptions and figures.

Such practices sap the foundation of science.

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